BLAST HAZARD FROM LOW LOADED MULTICELLULAR MAGAZINE

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ABSTRACT

In the case of a large number of companies or laboratories dealing with explosives manufacturing, a lot of small explosive charges waiting for being tested are stored in reinforced structure buildings with a specific design. The purpose of this study is to determine hazardous areas contours, according to the French Regulation definitions, in the case of an aboveground multicellular storage facilities involving 1.1 Hazard Division material. The limits of such hazardous areas are corresponding to an overpressure threshold, when the blast is the only effect to fear. The main feature of such storages is the low loading density lying between 0.01 kg/m^3 and 0.1 kg/m^3. Often, a barricade is built up in front of the magazine chambers to catch the fragments if an accidental event occurred. Its influence on hazardous areas shape and sizes, due to the blast, will also be assessed.

The best way to reach this goal was to perform scale model tests in order to record overpressure - time history all around the scale model, with piezoresistive gauges.

Hazardous areas limits as function of $Q^{1/3}$ (Q : TNT equivalent charge weight) have been deduced from these tests.

This study ended with a guide-book edition which explains and details each step of the method to be filled in order to apply these results to full scale storages by taking into account the loading density, the distance between the barricade and the building, ...

The overpressure - time history recordings, obtained during these tests for different situations,

- in free field, far from the scale model
- just behind a barricade
- in a focusing space, like the corridor between the barricade and the reinforced chambers façades

increase the NATO's data bank on the effects of an explosion which may be produced by a small explosive charge stored inside a reinforced structure magazine. These also could be used to better assess QD's for 1.1 Hazard Division small charges.

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1 - INTRODUCTION

According to the french labor Regulation, the presence of an HD 1.1 material, being stored or handled in a laboratory, makes necessary to define hazardous areas, depending on the level of potential damages caused on the persons and properties. For example, before starting a new explosive material manufacturing activity, a Safety Study must be carried out to ensure the total persons survival if an accidental explosion occurs. So, the hazardous areas contours must be known as precisely as possible by taking into account all the influential parameters (venting area, corridor, barricade, and s.o). Radius of hazardous areas are well known in free field. But sometimes, the rules proposed by the Regulation may appear unadapted for the configurations involving buildings with a specific design, implanted in a complex surroundings. This is the case of a great number of storage magazines which can be found in explosive manufactures or in some research centers. Often, the loading density of such storage magazines is quite low, which increases hazards assessment difficulty. Hazardous areas contours must represent the realistic safety distances in regard with the actuel hazard to be considered.

So, in order to comply with the Regulation for such storages, scale model tests have been performed which the principle was to measure overpressure close by the model. Explosive charges involved in these tests are supposed to produce only blast effect after detonating (no fragments or debris emitted).

2 - DEFINITION OF STUDY PARAMETERS

2.1. Loading density

Four loading densities were considered : 0.01 kg/m^3-0.03 kg/m^3-0.05 kg/m^3- 0.1 kg/m^3. They are representative of what it is really found inside storage chambers where very small explosive charges are temporality stored before being tested. This situation is especially usual in a research center like SNPE's one.

2.2. Model sizes

Model that has been used for the tests to represent aboveground multicellular storage magazine is made of a serial of identical chambers, each with a volume of 0.5 x 0.5 x 0.4 m^3. It has been chosen to perform **1/5 scale model tests** in regard with full scale chambers sizes (2.5 x 2.5 x 2 m^3).

Recall on scaling laws :

Let us suppose that $1/\lambda$ is the scale factor.

If P is the overpressure produced by a W explosive charge weight at x distance, so, P is also the overpressure produced by a W/λ^3 explosive charge weight at x/λ distance.

In term of scaled distance, the following relationship can be established :

$$\underset{\text{Scaled distance}}{\bar{d}} = \underbrace{\frac{x}{W^{1/3}}}_{\text{Full scale}} = \underbrace{\frac{x/\lambda}{(W/\lambda^3)^{1/3}}}_{1/\lambda \text{ scale}}$$

it is what it is usually called "Hopkinson's law", or "scaling laws" or simillitude equations".

By taking into account both loading densities and storage chamber volume, explosive charges weights which were involved during the tests are 1, 3, 5 and 10 g.

2.3. Scale model tests configurations

In order to simulate all the situations that could be found in the reality, five configurations were chosen :

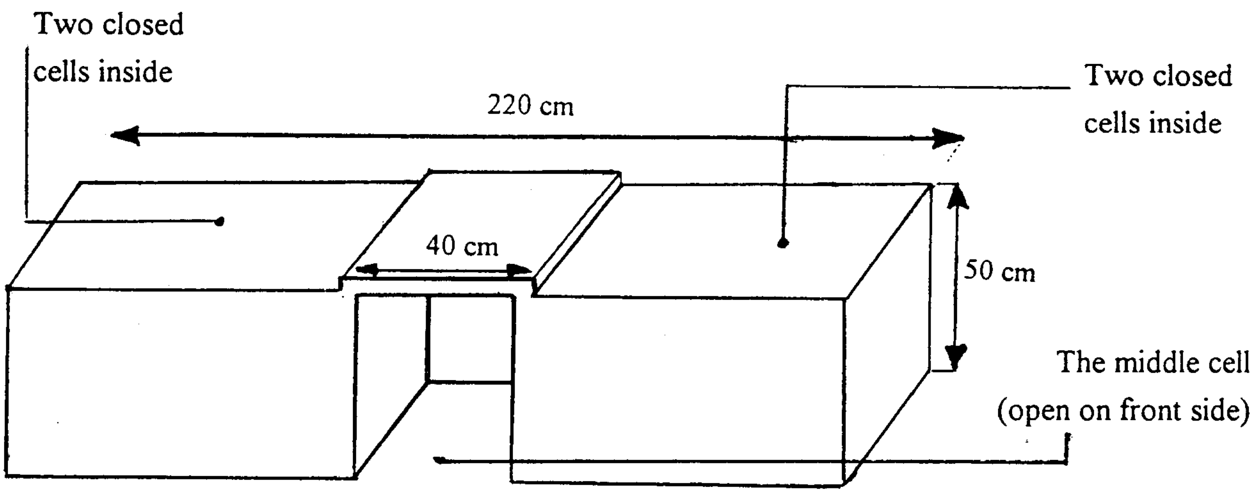
- Model with a vertical wall built up in front of the storage chambers to stop any kind of fragments. Two distances were considered : 32 cm and 62 cm (between the wall and the building façade),
- Model with a barricade, built up also in front of the storage chambers. Two distances were considered : 39 cm and 55 cm (between the top of the barricade and the building façade),
- Only the model.

3 - SCALE MODEL TESTS FEATURES

Since goal of the trials is to measure overpressure inside and around the model, experimental setup may be devided in three parts : the model, the explosive charge and the instrumentation.

3.1. Model - Wall - Barricade

Model which is representative of multicellular building consists of five identical chambers, each with a volume of 0.5 x 0.5 x 0.4 m^3. Only the middle chamber is used for the tests. Explosive charge is alway put inside it. The four others chambers are completly closed.



<u>Figure 1</u> : Multicellular model

The middle chamber is made up of a 60 mm thickness steel walls. The others have 20 mm thickness steel walls and are completely closed (figure 1). Steel was chosen so that the model does not lose its shape after each test and not because it is representative of the real chamber constitutive material.

In front of the model we can set up either a 0,7 m high and 20 mm thick vertical steel wall or an earth barricade, 45° sloping with the same height (0.7 m). The wall is hardened with flying buttresses (figure 2) and can be moved easely.

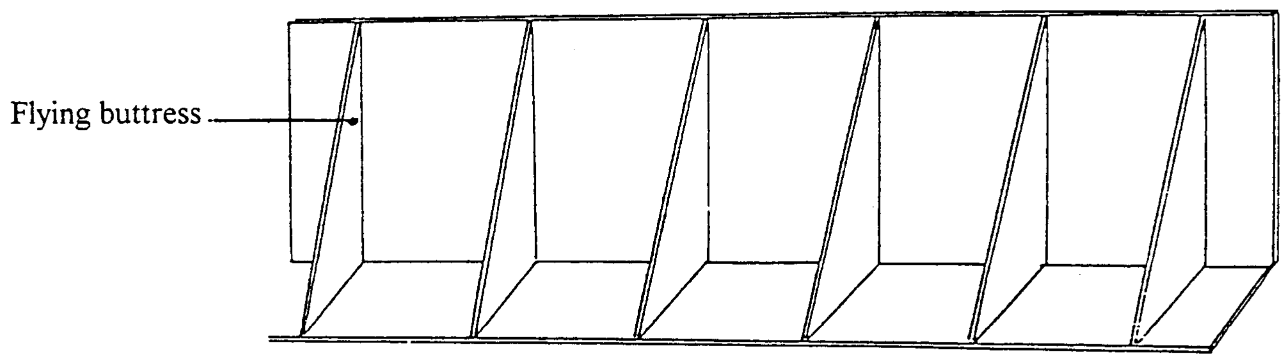


Figure 2 : Vertical steel wall

3.2. Explosive charges

In order to ensure a good reproducibility of the priming, RDX/Wax 98/2, pellet pressed, with a density of 1.6 g/cm^3 is used as explosive material for the charges involved in these tests. 1g, 3g, 5g or 10 g charges are either cylindrical, or hemispherical. A hole in each charge is dug to receive a small detonator Davey Bickford SA 4201 A/M 120 B, to minimize influence of detonator effect after its detonation.

3.3. Instrumentation

Overpressures were measured with piezoresistive gauges, fixed into a metal slab which laid down on the floor. So, gauges membrane is horizontal at ground level to measure static pressure. Figure 3 shows measurement points locations in regard with configuration that we want to study :

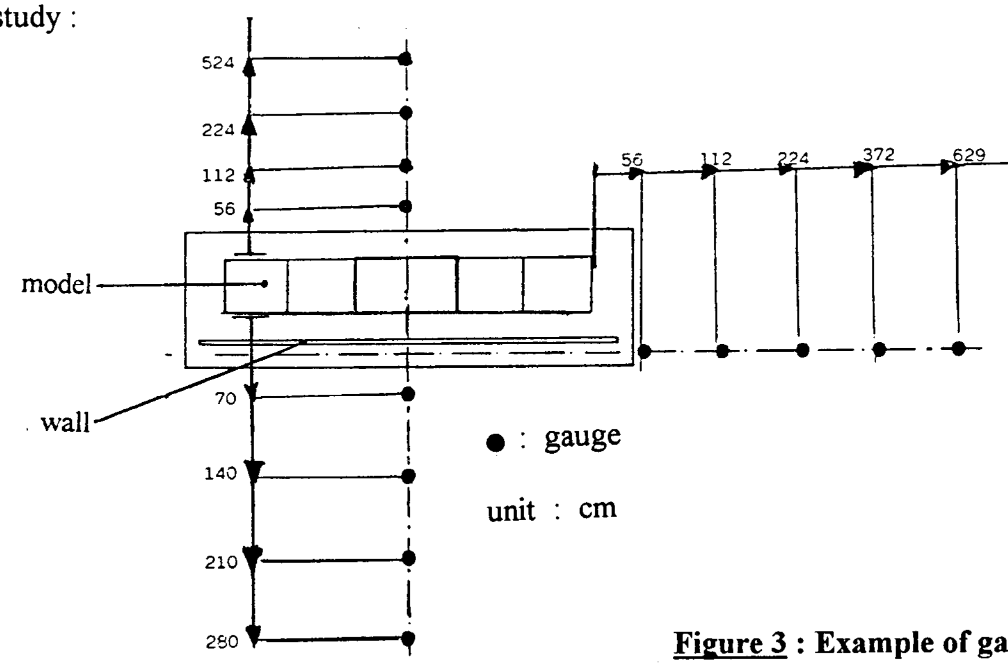
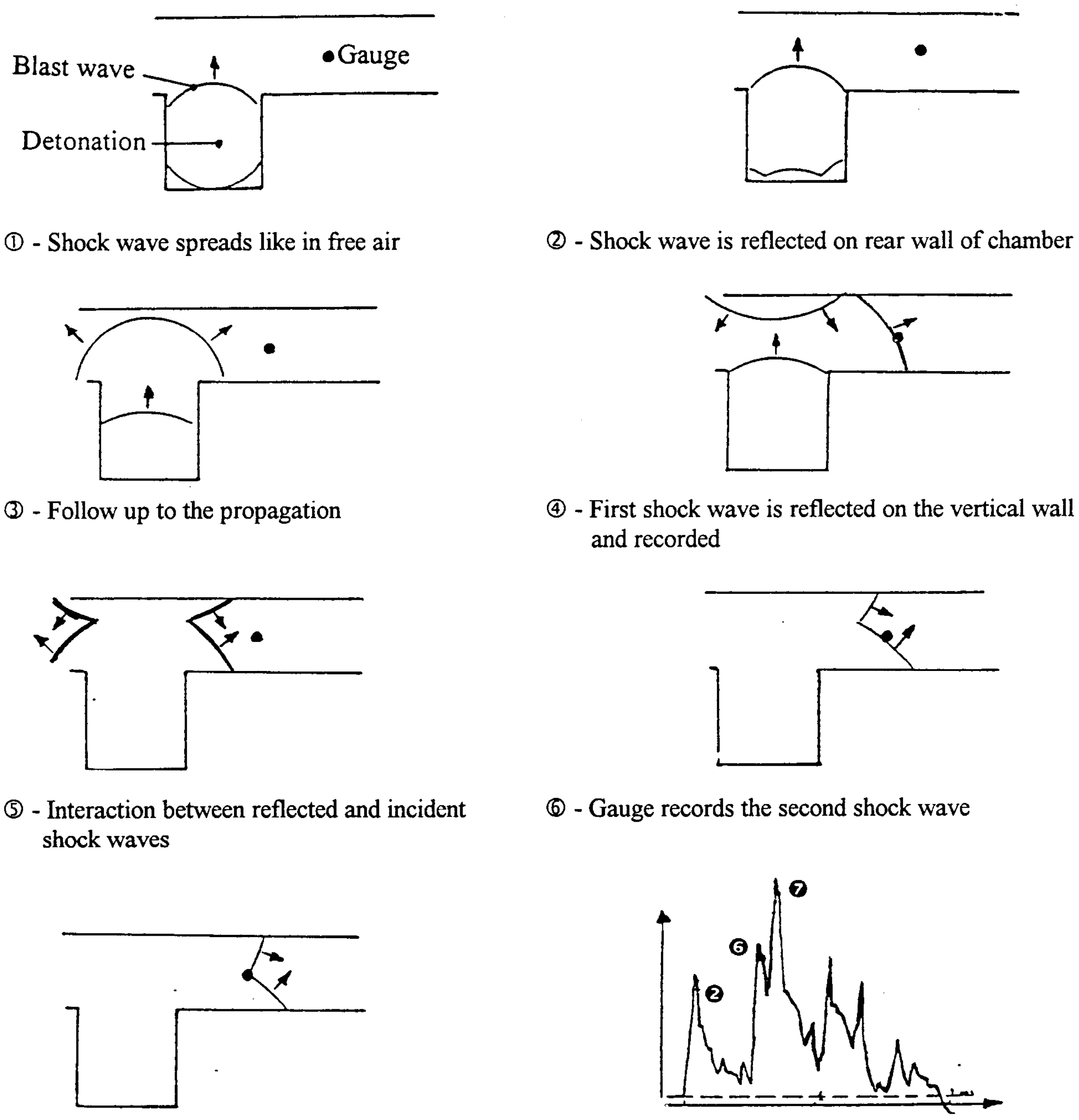


Figure 3 : Example of gauges locations

4 - RESULTS

4.1. Overpressure time-history

Because of the great complexity of surroundings when a barricade or a vertical wall is near the model, we expect to obtain an overpressure profile more or less well defined, made of several peaks due to the multiple reflexions against the different walls. As planned, figure 4 presents as an example, a typical recording of overpressure versus time.



① - Shock wave spreads like in free air

② - Shock wave is reflected on rear wall of chamber

③ - Follow up to the propagation

④ - First shock wave is reflected on the vertical wall and recorded

⑤ - Interaction between reflected and incident shock waves

⑥ - Gauge records the second shock wave

⑦ - the two shock waves are added and recorded

⑧ - Overpressure time-history

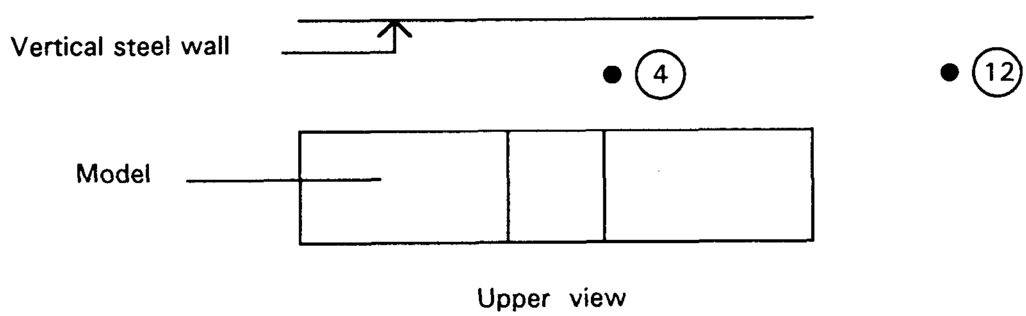
<u>Figure 4</u> : Overpressure profile recorded by a gauge located in the corridor between the model and the vertical wall

Generally, the second peak is the most intense because it is caused by a blast wave reflexion. For this study, only the most intense peak pressure which is due to either incident or reflected shock wave is taken into account, because the maximal overpressure causes the most severe damages on the human beings.

Reproducibility

Before bringing comments on the measurements, their reproducibility has been tested in function of the gauge location.

Let us consider two overpressure recordings examples coming from gauges n°4 and n°12 as shown on next figure :



explosive charges weight is 3 g.

Overpressure profiles obtained are presented hereafter :

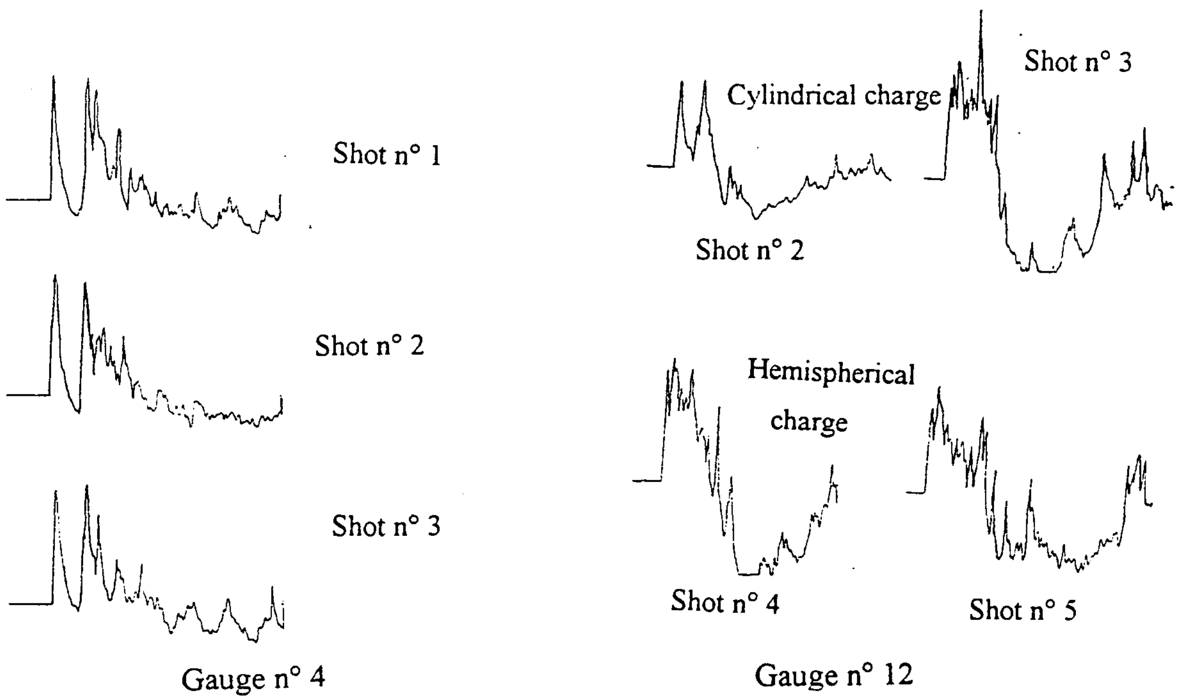


Figure 5

As we can see on the figure 5, measurements are well reproducible for gauge n°4. For gauge n°12, measurements seem satisfactory when hemispherical charges are tested. In revange, maximal overpressure are quite different in the case of cylindrical charges.

It does not mean that measurements reproducibility is greatly linked to the explosive charge shape. Others measurements, with other gauges, showed also slight differences between the results obtained from two identical shots.

The first explanation is that the explosive charge weights is so small that the least change of one of the test conditions (charge location, gauge orientation, vertical steel wall situation in regard with the model, ...) may lead to two different overpressure recordings. The second explanation is that gauge n°4 is near by the charge, in a confined space (between the vertical steel wall and the model). The shock wave is strong, dense not very extended and can not be easely disturbed by external factors. At the contrary, gauge n°12 is far from the charge and placed in free field. Intensity of the shock wave greatly decreases and it begins to be very extended. It becomes to be very sensitive to all external changes.

Each test was performed two times, and only the highest overpressure value was kept back.

4.2. Hazardous areas

french Regulation hazards areas definitions are :

	Z1	Z2	Z3	Z4	Z5
Foreseeable personal injury	Lethal injury in more than 50 % of cases	Serious injuries which may be lethal	Injuries	Possibility of injuries	Very low possibility of slight injuries

When the airblast is the only effect to fear, the Regulation proposes to assimilate hazardous areas limits to isobars, as precised hereafter :

$$Z1 / Z2 = 600 \text{ mbars}$$
$$Z2 / Z3 = 300 \text{ mbars}$$
$$Z3 / Z4 = 100 \text{ mbars}$$
$$Z4 / Z5 = 50 \text{ mbars}$$

It also presents them as function of $Q^{1/3}$ where Q is the TNT equivalent charge weight.

For 1.1 Hazard Division material it is written that :

$$R1 = 5\ Q^{1/3}$$
$$R2 = 8\ Q^{1/3}$$
$$R3 = 15\ Q^{1/3}$$
$$R4 = 22\ Q^{1/3}$$
$$R5 = 44\ Q^{1/3}$$

The two ways for defining hazardous areas limits are equivalent in free field, but it is no more true when obstacles or walls are standing near by the charge.

So, what it is proposed in this study is to assess hazardous areas contours only with overpressure measurements achieved in the field. After this first stage, we present these limits as function of $Q^{1/3}$ in order to make a quick comparison with regular ones.

It is important to precise that the purpose of this study is not to analyse, in depth, interaction between shock wave and barricade or vertical wall ; instrumentation is not enough sophisticated and complete. It is just a question of assessing shape and sizes of hazardous areas. In some cases, the number of measurements points has shown itself insufficient to deduce easely the contours of these zones, so, we did not hesitate to over-estimate their sizes when necessary. As an example, figure 6 presents a comparison between what we have obtained in the case of a vertical steel wall placed 0.62 m away from the building façade and the hazardous areas proposed by the Regulation for the same explosive weight, in free field.

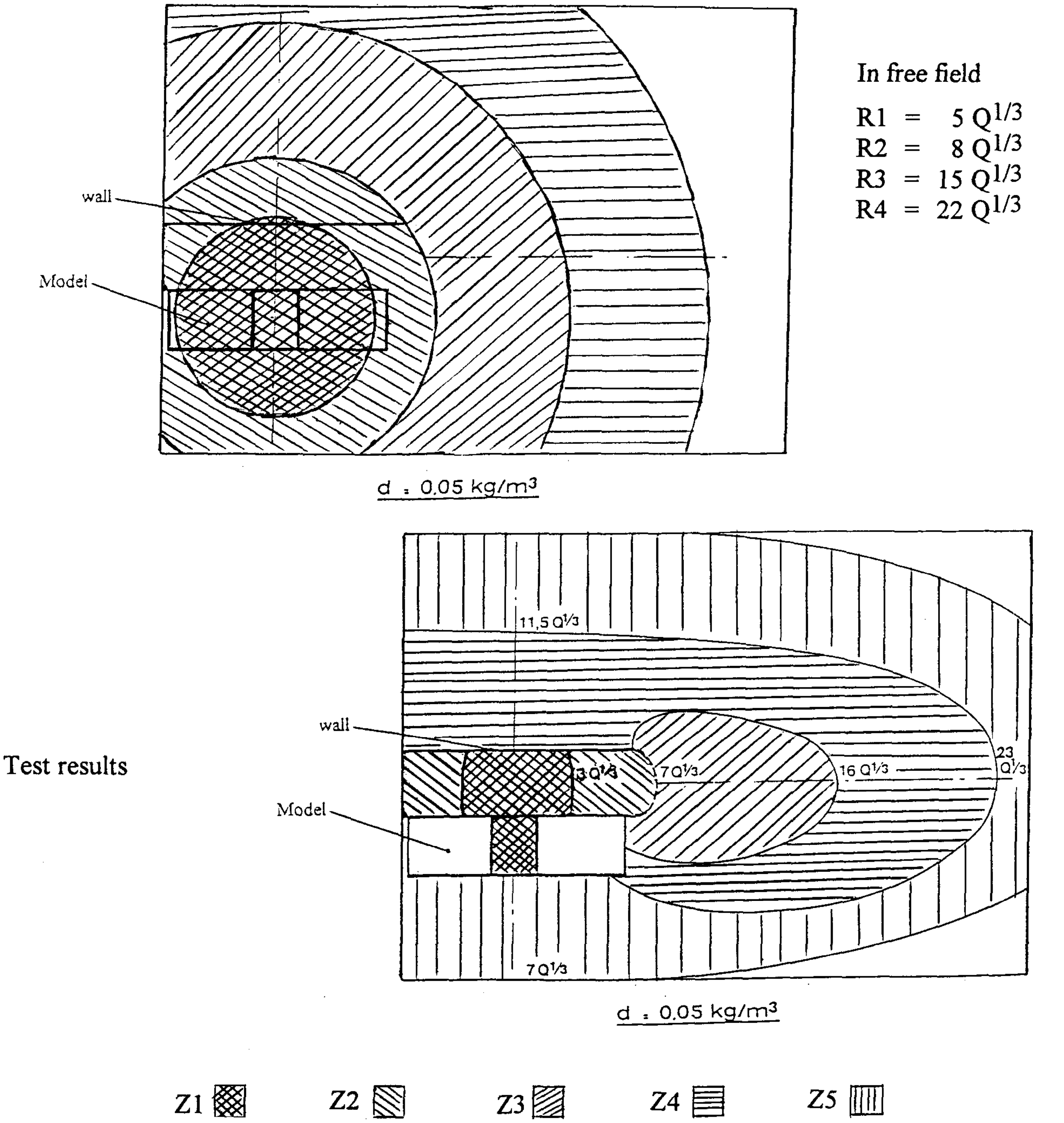


Figure 6 : Comparison between experimental results (model + vertical steel wall) and what is proposed by the Regulation for the same explosive charge in free field.

Within the framework of this study, several figures (by taking into account loading densities and the presence (or not) of barricade or vertical wall) of this type were drawn.

General remarks that we can make after plotting hazardous areas from all the configurations, are :

- the vertical wall tends to reflect the pressure when barricade has a small influence on shock wave propagation,
- in regard with surroundings, hazardous areas limits are different to these proposed by french regulation in free field. It was what we expected, but we did not know in what proportion.

4.3. Application to full scale configurations

The big interest of these scale model tests results is that we can apply them to a great diversity of configurations close to these tested in this study. But in order to select correctly the configurations that which may be taken into account as a reference, it is necessary to respect the following points :

- loading density ρ must be included between 0.01 and 0.1 kg/m^3 :

$$0.01 \text{ kg/m}^3 \leq \rho \leq 0.1 \text{ kg/m}^3$$

where $\rho = \frac{Q}{V}$

with : Q = TNT equivalent charge weight
V = volume of storage chamber

- distances between explosive charge and vertical wall or barricade must be included in a domain defined by :

For the vertical wall :

$$0.52\,(10.\,Q/\rho)^{1/3} \leq x \leq 0.82\,(10.Q/\rho)^{1/3}$$

For the barricade :

$$0.59\,(10.\,Q/\rho)^{1/3} \leq x \leq 0.75\,(10.Q/\rho)^{1/3}$$

Where ρ is the loading density and Q, the full scale TNT equivalent charge weight.

We consider that the results obtained from these tests, involving only two distances between the vertical wall and the model facade (or the barricade and the model facade) may be extended to all distances between these two distances.

Explanations

The scaling law gives :

$$\underset{\text{Scaled distance}}{\bar{d}} = \underbrace{\frac{X}{Q^{1/3}}}_{\text{Full scale}} = \underbrace{\frac{X_1}{Q_1^{1/3}}}_{\text{Reduced scale}}$$

From which, we deduce :

$$\frac{X}{X1} = \left(\frac{Q}{Q_1}\right)^{1/3} = \left(\frac{\rho V}{\rho V1}\right)^{1/3} = \frac{V1/3}{V1^{1/3}} \left(\rho = \frac{Q}{V} = \frac{Q1}{V1}\right)$$

now V1 = 0.1 m^3 (volume of the middle cell)

Then $X = X1\ (10.Q/\rho)^{1/3}$

In our study, in the case of the vertical wall, as we have $0.52\ m \leq X1 \leq 0.82\ m$, we obtain finally :

$$0.52\ (10.Q/\rho)^{1/3} \leq X \leq 0.82\ (10.Q/\rho)^{1/3}$$

- Height of barricade or vertical wall must be at least equal to 3.5 m
- Storage chamber must be cubic or quasi-cubic.

5 - PRACTICAL RESULTS EXPLOITATION

In order to apply results of these scale model tests to full scale configurations that we want to treat, we have to lead the following actions :

1 - Calculation of loading density ρ (kg/m^3)

2 - If there is neither barricade no vertical wall we use hazardous areas plotting corresponding to the calculated loading density. So, we apply A $Q^{1/3}$ functions which are written on the diagram to the full scale charge, by respecting hazardous areas contours.

Il there is a vertical wall or a barricade, first we have to check its height (about 3.5 m), and after calculate X_0 :

$$X_0 = X_1 - 0.2 = X\ (0.1\ .\ \rho/Q)^{1/3} - 0.2$$

↑

scaled distance between charge and model facade

Then, we compare X_0 to values chosen for the tests :

- 0.32 m or 0.62 m for the vertical wall,
- 0.39 m or 0.55 m for the barricade

3 - In regard with the kind of screen (barricade or vertical wall) we choose the nearest value from X_0.

4 - Select corresponding hazardous areas plotting.

5 - Apply AQ1/3 functions to full scale charge in order to deduce hazardous areas limits, by respecting their contours.

6 - CONCLUSIONS

➔ With both overpressure measurements around the model and french Regulation criteria which propose to define hazardous areas limits as isobars, it was possible to assess contours of hazardous areas for an aboveground multicellular storage building with low loading density (lying between 0.01 kg/m^3 and 0.1 kg/m^3).

➔ These limits were plotted as precisely as possible and were over-estimate when measurement points were missing (in account of gauge failure).

➔ Maximal overpressure value even in the case of multiple reflexions is the only parameter taken into account for deducing hazardous areas limits.

➔ These results confirm that SNPE masters all what is concerning overpressure measurements in the field. Moreover, several studies on interaction between blast wave and varied obstacles have shown that our predictive models on blast wave propagation were quite satisfactory. So, our experimental means (overpressure gauges, model, ...) combined to our predictive tools permit us to analyse all configurations that we want, without any limitations on explosive charge weight and storage facilities design complexity.